A BETA ATTENUATION TRANSMISSION SYSTEM (BATS)*

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Abstract

The beta attenuation transmission system (BATS) is an automated radiation gauge designed for quantitative measurement of component thickness in explosive detonators. The BATS was designed and built by Group M-1, the Nondestructive Testing Group, of the Los Alamos Scientific Laboratory to measure the areal thickness, in mg/cm², of a cylinder of high explosive (HE) enclosed within a plastic holder. The problem is to determine the density of the HE.

A ^{90}Sr source is collimated by a 0.25 x 1.59-mm slit, and the transmitted beta-particle flux is detected by a plastic scintillator, coupled to a photomultiplier tube. The detonator is transported through the radiation beam by a leadscrew, ballnut, stepping-motor combination. Continuous analog position data are available, derived from the output from a linear-actuated potentiometer attached to the scanner. A linear electrometer amplifies the detected signal, which is then integrated for a preselected time, to obtain the desired statistical accuracy.

A microprocessor (uP) is used to control the scanner position and to make the data readings at the assigned positions. The data are stored, and, at the completion of the scan, are processed into the desired format. The final answer is displayed to the operator or output to a peripheral device for permanent record.

This paper will present, in detail, the characteristics of the radiation source, the collimator, the signal detection and conditioning, and the final results. The scanner and the microprocessor control system will be briefly outlined.

I. INTRODUCTION

The measurement system described here is an automated radiation gauge designed especially for the quantitative measurement of the density of a high explosive in a Los Alamos Scientific Laboratory detonator. The proper operation of the detonator can be assured only if this density is known. The basis for the measurement is the transmission/absorption of a stream of beta-particles by low atomic number (Z), low density (ρ), organic materials - plastic and the high explosive.

The inspection system consists of several, rather discrete, components, each of which is described in the following sections - the source/collimator, the detector, the signal-processing electronics, and, finally, the output device.

The detonator is a Lucite cylinder 3.18-mm o.d. x 1.5 mm-i.d. and a length of 5 mm. The detonator attenuates about 93% of the beta beam.

A block diagram (Fig. 1) shows the basic interconnection of the system.

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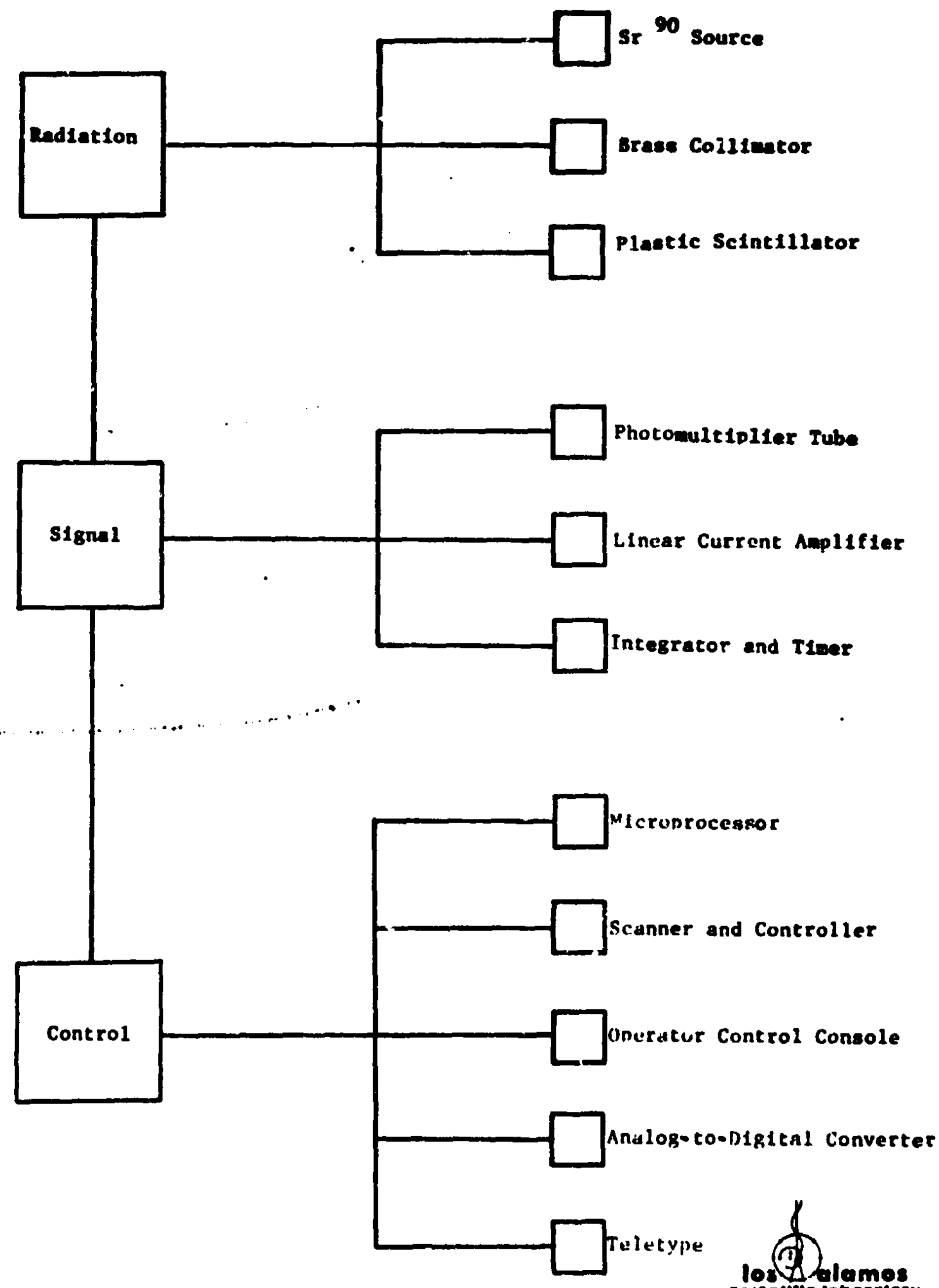

Fig. 1 System Block Diagram

2. SOURCE AND COLLIMATOR DESIGN

The radiation source was chosen on the basis of the material thickness, density, and atomic number of the object to be inspected. By experiment, it was determined that the isotopic combination, strontium-90/yttrium-90, was the best choice, both for the high energy beta particle (2.28 MeV) and long half-life (28.8 years). This particular source was readily available from commercial vendors. The collimator design was such that the entire HE column was spanned by the beta-particle beam in order to minimize the effects of slight positioning variances.

The source capsule is 2-mm diam by 2-mm height with an activity of about 28 mCi. It is contained within the collimator assembly by means of a set screw.

The collimator assembly (Fig. 2) is machined from four brass blocks that are pinned together to form a cube 5.08-cm square. The collimator is two stage, with one stage above and one below the sample. These are 0.25-mm slits that have a width of 1.59 mm and a length of 2.54 mm. The total source-to-detector distance is 14.1 mm.

3. DETECTOR

The detector assembly (Fig. 3) is a plastic scintillator coupled to a photomultiplier tube. The scintillator is a cylinder 0.64-cm diam by 4.5-cm length and is a LASL produced material selected for its near nonexistent delayed fluorescence. The light shield is beryllium 0.2-mm thick.

The photomultiplier tube, an EMI Type 9662B, is preselected for low dark current, low noise, and

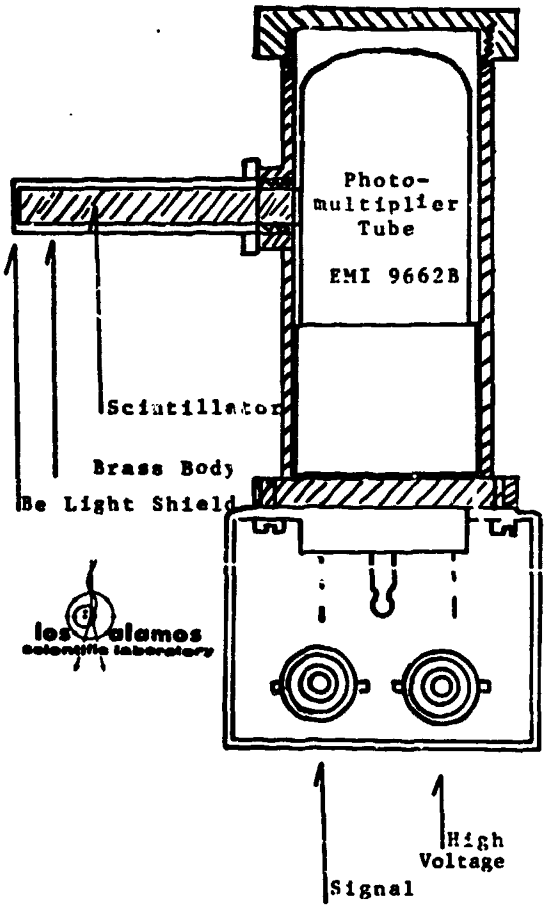

Fig. 3. Detector assembly.

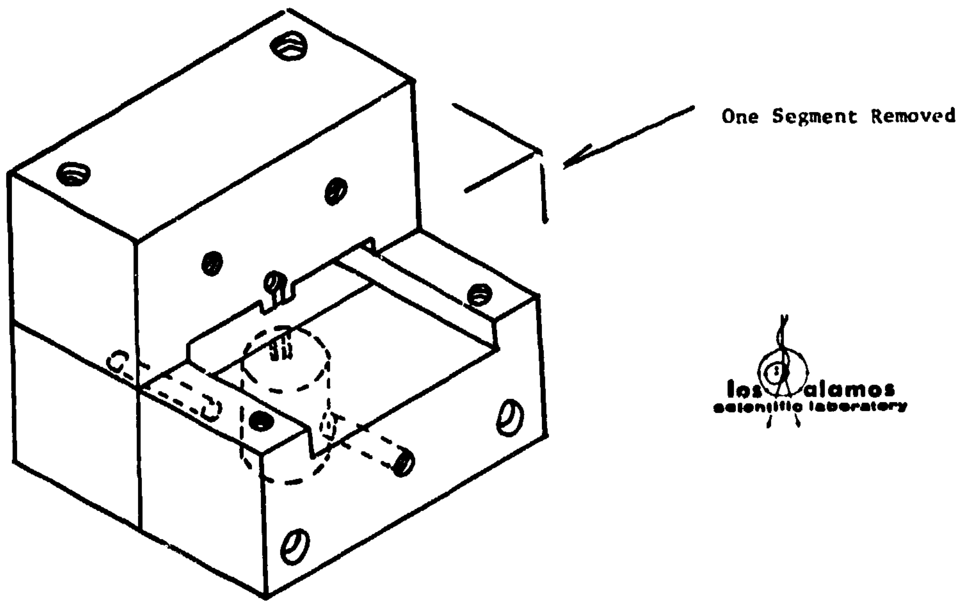

Fig. 2. Collimator assembly.

high gain. It is wired to output a current proportional to input light. Typical operating voltages range from -800 to -900 Vdc. A dc-current method rather than pulse counting was chosen because it allowed signal averaging. The electrometer used to amplify the signal has a long time constant, about 0.1 s so that noise pulses of short duration, less than 0.1 s, are not seen on the electrometer output.

A lead shield 31.8-mm thick, 12.7-mm o.d. by 3.18-mm i.d., is inserted between the detector and the secondary collimator to shield the detector from bremsstrahlung.

The resulting assembly exhibits an edge effect of 0.1 mm as shown in Fig. 4. This shows that effective readings may be made to within 0.1 mm of the edge of the test object, Fig. 4.

4. DATA SIGNAL FLOW

The signal flow is as follows, see Fig. 5. The beta particles are emitted from the source. Those transmitted through the sample (about 7%) are absorbed in the scintillator which emits light. This is detected by the photomultiplier. a low-level current is generated (about 1nA), and input to a linear current amplifier. The output of which is input to an integrator.

Upon receipt of a Start Integrator signal, a logic sequence is initiated. This resets the integrator and timing circuits to zero and starts both operating. At the end of the timing period the integrator is put into a hold mode and a signal is sent to the ADC to start conversion. The ADC, upon completion of the conversion, signals the μP to read the digital number. The μP then either stores or processes the number and displays it in units of gm/cm^3. The position

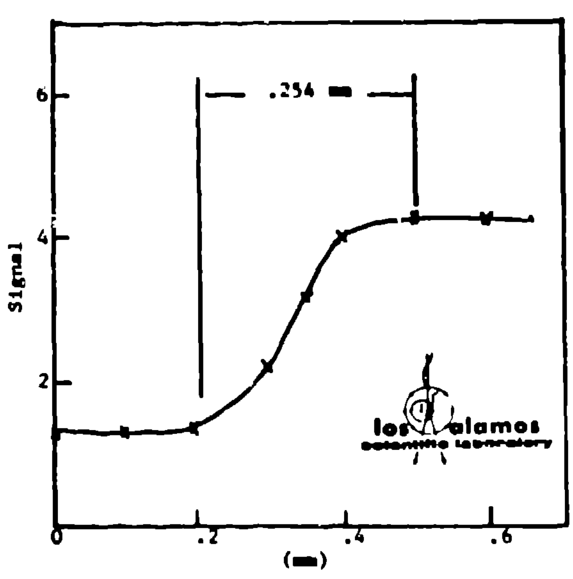

Fig. 4. Collimator edge effect.

of the data reading is displayed simultaneously. Both data and position may be output to the teletype.

The integrator is composed of two field effect operational amplifiers (Harris HA-2524). One is wired as an integrator, the other is used as a sample and hold circuit. Together, these form a unit that resets to zero, integrates, and then goes into a Sample-and-Hold mode. Integrator linearity when a constant voltage is applied is as shown in Fig. 6.

The timing control is based on a 1 MHz crystal oscillator divided down to give 0.1-s pulses. A counter counts 0.1-s pulses until a comparison is made with the integration time interval entered into a set of thumb wheel switches. Time is variable from 0.1 to 99.9 s in 0.1-s steps.

5. CONTROL

The control system is composed of standard items and will not be discussed in great detail.

The main item of interest is the μP, an Intel 8080, with Teletype input and output. External to the μP is the analog-to-digital converter (ADC), a Deltex 835, with eight addressable input analog ports and ten-bit output.

The scanner (Fig. 7) is a ball-nut stepping motor drive. The stepping motor drive incorporates a momentary electronic brake. This prevents the scanner from overrunning a position. Position is determined by digitizing an analog voltage obtained across a linear potentiometer attached to the scanner. Repeatability of position is shown to be ± 0.05 mm.

In the Manual Mode the scanner is controlled by the operator from the scanner control chassis (Fig. 8). The Auto Mode controls are run by the μP. The operator console (Fig. 7) contains readouts for position, data, status and three switches - initilize, start, and abort. Permanent record is made by outputing data to a Teletype.

6. INSPECTION PROCEDURE

The BAT, upon receiving an Initilize signal from the operator, will run the built-in step wedge and generate a set of curve fit constants that are stored in the μP memory. An entire lot of items will be inspected using this set of constants.

A Start signal from the operator causes the processor to take four readings on a reference step. The average of the four readings is compared with the value for this step obtained during the Initilize run. If it is within ± 10%, the processor then calculates a correction factor. Four readings are made at each of three locations on the detonator. The mean of each of these three readings are then multiplied by the correction factor to correct for bias. Four readings are then made on the reference step and compared with its

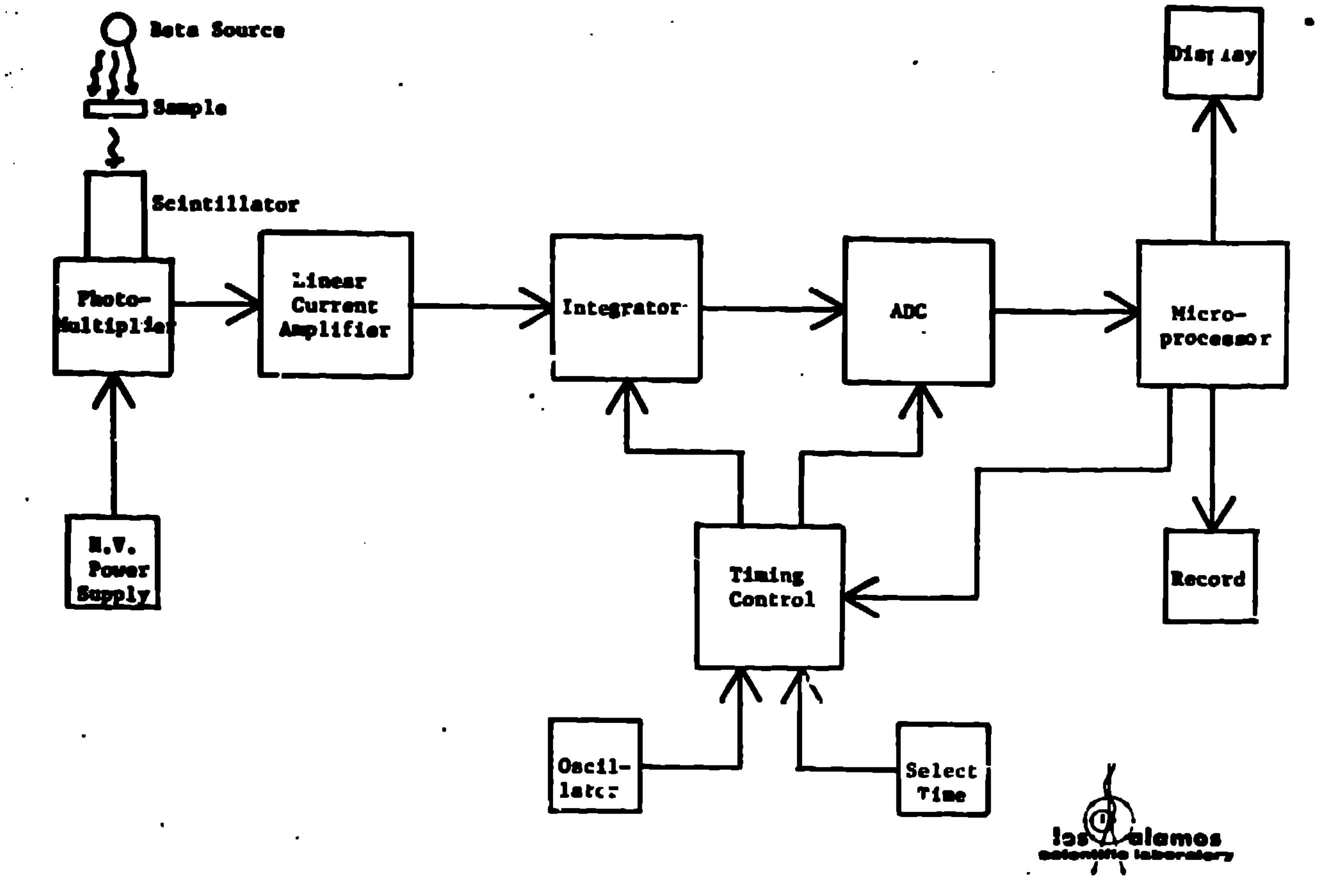

Fig. 5. Signal flow path.

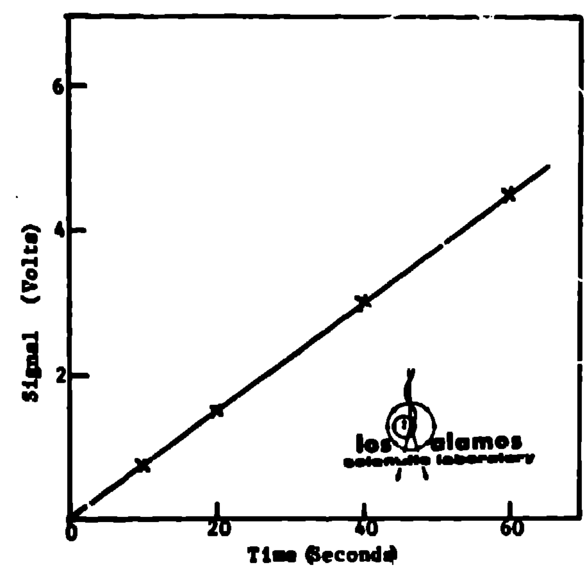

Fig. 6. Integrator (Constant 1 nanoampere input to linear current amplifier).

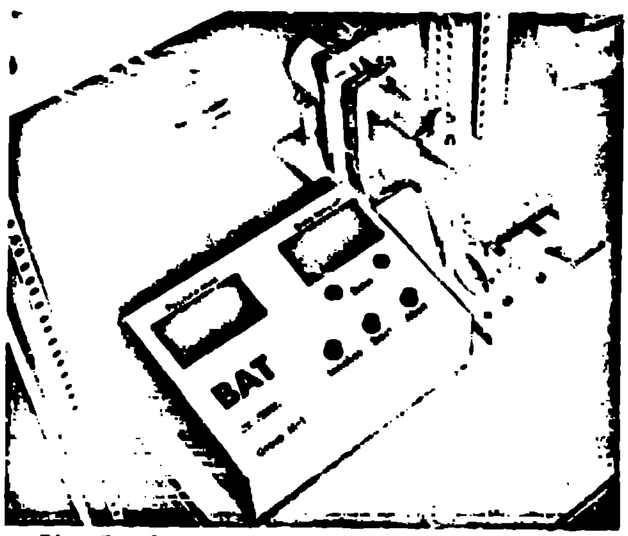

Fig. 7. Operator console and scanner.

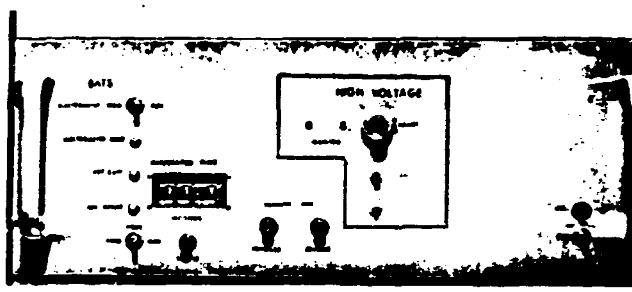

Fig. 8. Manual control panel.

value at the start of the inspection. System drift is then calculated and each data point corrected for system drift.

The corrected data is then converted to density and output to the Teletype.

7. CALIBRATION

Two variables have to be calibrated the location of the data readings on the detonator and the density of the HE.

The scanner position is continually monitored by the μP. As the detonator is carried by the scanner, a means of precisely correlating the location of data readings on the detonator to scanner position, had to be found. A standard detonator was made and holes (0.15 mm d[illegible] were drilled in it at given locations. Scanning this standard verified that position readings would reproduce to within ± 0.05 mm.

The HE density values for the detected signal were obtained by fabricating a series of detonators that spanned the expected density range. Weight measurements on the standard detonators before and after loading with HE yielded the HE weight. As the volume was known, it became a simple calculation to determine the density in gm/cm^3.

Once a master calibration curve was determined, a Lucite step wedge (secondary standard) was machined that yielded signal levels spanning the densities of interest, 1.40 to 1.60 gm/cm^3. Density values were assigned to each step corresponding to its transmitted signal value. This step wedge was installed in and became a permanent part of the transport mechanism. A linear curve fit was determined to best define the shape of the calibration curve, see Fig. 9.

8. RESULTS AND SUMMARY

System sensitivity is a 3% signal change for a 1% HE density change. System accuracy has proven to be ± 0.025 gm/cm^3. This was determined by running the calibration standards a number of times and computing the mean and standard deviation for each item.

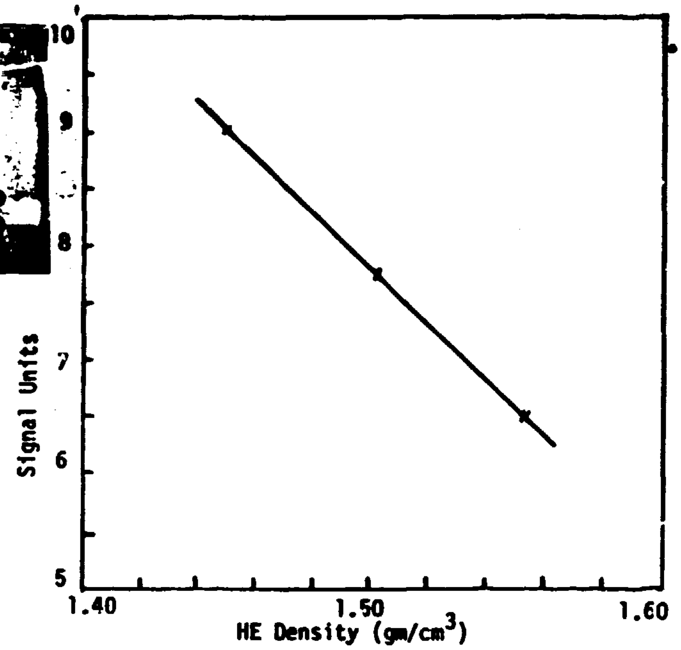

Fig. 9. Calibration curve.

In summary, the use of a μP has provided the control and data reduction capabilities to yield on-line, accurate data with a minimum of operator time and interaction.

A high intensity beta source of long half-life has proven to give high sensitivity and long-term stability.

A photograph of the system is included, see Fig. 10.

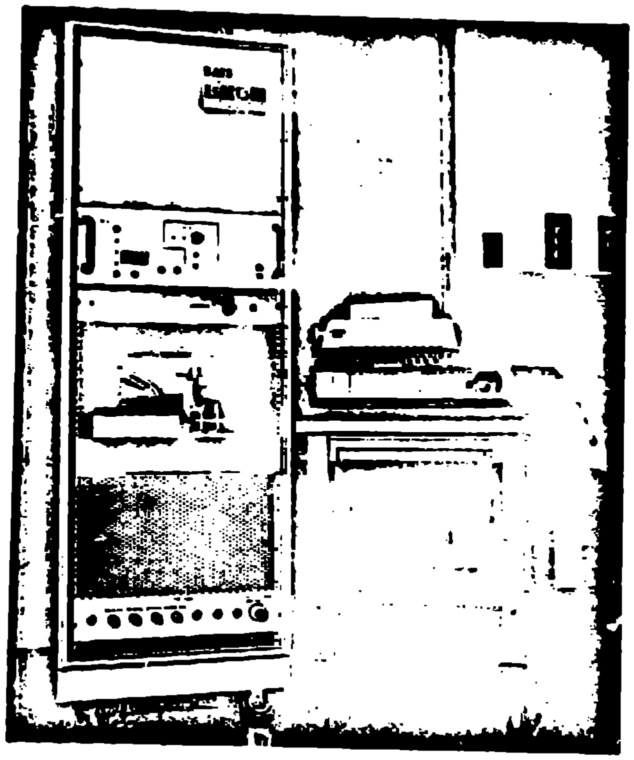

Fig. 10. BAT system.